ESTIMATES OF STATUS AND TREND FOR SFAN JUVENILE COHO SALMON

Report by:

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San Francisco Area Network (SFAN) monitors juvenile Coho salmon populations within three coastal watersheds in Marin County: Olema Creek, Redwood Creek, and Pine Gulch Creek. Estimates of annual status and trends over time are desired for assessing management goals. The survey design, status estimation, and a power analysis to detect trends in juvenile Coho abundance over time are addressed in this report.

1. Survey Design

The current survey design for juvenile Coho combines a systematic sample of pools located within the mainstem of Olema, Redwood, and Pine Gulch Creeks and annual surveys of index reaches. Equiprobable general systematic sampling (GSS) of pools is used to estimate juvenile Coho abundance within each watershed. A random start pool is chosen and every fifth pool is surveyed by snorkeling the pool in a single pass. Because water quality in smaller tributaries is not conducive to snorkel surveys, only the mainstems within each watershed are surveyed. Occasionally GSS sites will fall onto index sites. In 2007, 3 to 5 index reach pools within each watershed were also selected in the GSS sample. In 2007, a bound-and-count calibration method was used for a random subsample of pools within Olema Creek.

Eight index reaches lie within both Olema Creek and Pine Gulch Creek, and 7 index reaches are located within Redwood Creek. Index reaches are approximately 100 m long and contain two to ten contiguous habitat units of which pools are both snorkeled and electrofished. Electrofishing occurred on the day following the snorkel survey (Del Real 2008). Because index reaches were subjectively chosen, the scope of statistical inference for estimates obtained from these surveys is limited to only the index reaches.

2. Current Status Estimation Methods

2.1 Status Estimation for GSS sites

SFAN personnel want basinwide estimates of juvenile population in pools for all three watersheds. Single-pass snorkel surveys have been shown to be biased low, accounting for only 40% of the true number of fish present (Rodgers, et al. 1992). The methods of Hankin and Reeves (1988) use a ratio estimator that exploits a more accurate method of detection as the basis for calibration. SFAN personnel apply the Hankin and Reeves (1988) method by using the electrofishing results from index reaches to adjust single-pass snorkel survey counts of the systematically chosen sites.

Beginning in 2007, SFAN conducted bounded count surveys in Olema Creek as an alternative calibration technique. This method is taken from an unpublished reference and involves random subsampling of GSS sites in multiple-pass snorkel surveys. SFAN personnel were concerned that observers would apply extra survey effort in index sites that were known to be used for calibration. In the bounded count method, surveyors are only told after the first pass that a particular pool will be surveyed further. The bounded count estimator is defined as follows:

$$\tilde{y}_B = d_{[m]} + \left(d_{[m]} - d_{[m-1]} \right),$$

where $\tilde{y}_B$ is the bounded count estimator of abundance and $d_{[m]}$ represents the observed maximum dive count from the *m* snorkel passes within a pool. This method is not applicable in Redwood Creek and upper reaches of Olema Creek where pools are smaller. In these pools, the first snorkel pass may disturb silt so that subsequent passes are not possible.

The current approach is to use the ratio of the basinwide index reach estimate and the sum of single-pass snorkel counts across all index reaches within a watershed as the ratio estimate for calibrating snorkel counts from the systematic random survey as in Hankin and Reeves (1988). Define the following terms as:

N is the total number of pools within a watershed;
n is the GSS sample size;
n' is the subsample size such that $n' < n$;
d_i is the diver count for pool *i;*
$\hat{R}$ is the ratio estimate of *R*, the true ratio of fish present to snorkel count; and
y_i is the true count for pool *i*.

The pool-level estimate of abundance is given by:

$$\hat{y}_i = d_i \hat{R}, \text{ for } i \text{ not in } n',$$

where

$$\hat{R} = \frac{\sum_{i=1}^{n'} y_i}{\sum_{i=1}^{n'} d_i}, \text{ for } i \text{ in } n'.$$

Hankin and Reeves (1988) provide the following estimated variance formula for the pool-level estimate:

$$\hat{Var}\left(\hat{y}_i\right) = \hat{R}^2 \hat{V}\left(d_i\right) + d_i^2 \hat{V}\left(\hat{R}\right) - \hat{V}\left(d_i\right) \hat{V}\left(\hat{R}\right),$$

where

$$\hat{V}\left(\hat{R}\right)=\frac{N-n'}{Nn'\bar{d}^2}\frac{\sum_{i=1}^{n'}\left(y_i-\hat{R}d_i\right)^2}{n'-1}.$$

For snorkel surveys with a single observer (i.e., assuming $\hat{V}(d_i)=0$), the variance of the pool-level estimate is simply:

$$Var\left(\hat{y}_i\right)=d_i^2\hat{V}\left(\hat{R}\right)$$

The form of the variance of the ratio estimate is based on the assumption that the precise measure used for calibration is a raw count. Because the ratio estimate is calculated from model estimates of abundance from MicroFish (Van Deventer and Platts 1983), $\hat{V}\left(\hat{R}\right)$ should account for both the deviations from the ratio-predicted counts and the variances of the modeled pool-level abundance estimates. The variance calculated in the current method will underestimate the true variance of the ratio estimator because of this added model variability.

The total number of fish within a watershed may then be calculated as:

$$\hat{Y}=\frac{N}{n}\sum_{i=1}^{n}\hat{y}_i$$

with variance

$$Var\left(\hat{Y}\right)=\frac{N(N-n)}{n(n-1)}\sum_{i=1}^{n}\left(\hat{y}_i-\hat{\bar{y}}\right)^2+\frac{N\sum_{i=1}^{n}V\left(\hat{y}_i\right)}{n},$$

where

$$\hat{\bar{y}}=\frac{1}{n}\sum_{i=1}^{n}\hat{y}_i.$$

2.2 GSS Status Estimation Issues

A major drawback of the SFAN ratio estimator application is that a true subsample of pools is not selected from the GSS sample for calibration by electrofishing. The use of index sites as the calibration data set does not meet the definition of a double sample, which is recommended by Hankin and Reeves (1988). If index reaches have been subjectively selected for juvenile Coho monitoring because of reasons associated with juvenile Coho abundance, then the calibration technique is likely to be biased. If index reaches were originally selected because they were located in acceptable juvenile Coho habitat and large numbers of juvenile Coho were likely to be found there, then the ratio estimator will likely overestimate the true population size.

The use of a true double sample is highly recommended for calibration. The ratio estimator is structured to have both sets of measurements made on the same units, so taking a subsample of GSS sites for the more accurate measurement is very important. If survey resources are limited, then perhaps the GSS sample size could be decreased slightly or some index reaches could be snorkeled only to make electrofishing resources available.

These authors can suggest no statistically acceptable way to justify using the index reach observations as a calibration data set unless a pilot study indicated otherwise. A pilot study in which a true subsample is drawn from the GSS sites would allow proper application of the Hankin and Reeves (1988) method. These estimates could be compared to those obtained when the index reach data set is used for calibration and an estimate of bias may be obtained. If the pilot study could be conducted every 3 to 5 years, then SFAN personnel could determine whether bias changes over time.

A pilot study may also be helpful in assessing the differential bias between the two calibration methods used by SFAN. It is unlikely that electrofishing and bounded count surveys are subject to the same error. If bounded counts surveys will become widely used by Coho managers in the future, then this research would certainly be useful to many agencies.

Elliot and Haviland (2007) use a pilot study to measure bias of a convenience sample in relation to a probability sample. The bias is then used to weight the estimates from each sample in a composite estimator so that an unbiased estimator may be obtained while incorporating the less-expensive judgment sample.

2.3 Status Estimates for Index Reaches

All pools within index reaches are both electrofished and snorkeled. SFAN personnel use MicroFish software to obtain an estimate of population abundance for each pool within each index reach. MicroFish software is based on removal-depletion methods to account for detection error. The program calculates a maximum likelihood estimate of the population total and provides a variance estimate for the model adjustment of raw counts. This abundance estimate applies to the population of index reaches within a basin.

SFAN personnel are interested in summarizing pool-level estimates to the index reach level and obtaining confidence intervals for each index reach. We suggest calculating total abundance and the associated variance estimate as follows:

$$\hat{T}_b = \sum_{i=1}^{n} t_i \ ,$$

where t_i is the estimate of total juveniles in pool *i*, *n* is the number of pools within the basin, and $\hat{T}_b$ is the estimate of juvenile abundance within an index reach. Assuming independence among pool counts within a reach, the variance of $\hat{T}_b$ is then:

$$Var\left(\hat{T}_b\right) = Var\left(\sum_{i=1}^{n} t_i\right) = \sum_{i=1}^{n} Var\left(t_i\right) = \sum_{i=1}^{n} \hat{\sigma}_i^2 \ ,$$

where $\hat{\sigma}_i^2$ is the estimated variance of juvenile abundance at pool *i*. The assumption of independence among pool counts within an index reach is likely tenuous, and estimated variances may underestimate the true variance if pool counts are positively correlated in space.

4. Power analysis for trend

The power analysis is conducted using the basinwide abundance estimates. While these estimates of status are subject to bias as described above, if one can assume that the bias is consistent across time, then the bias should not greatly impair the ability to detect trends in abundance over time. However, trend analyses of unbiased estimates are always preferable. This is a preliminary power analysis that should be re-evaluated once status estimates are available that do not suffer from the current flaws discussed in Section 2.2.

4.1 Pilot Data

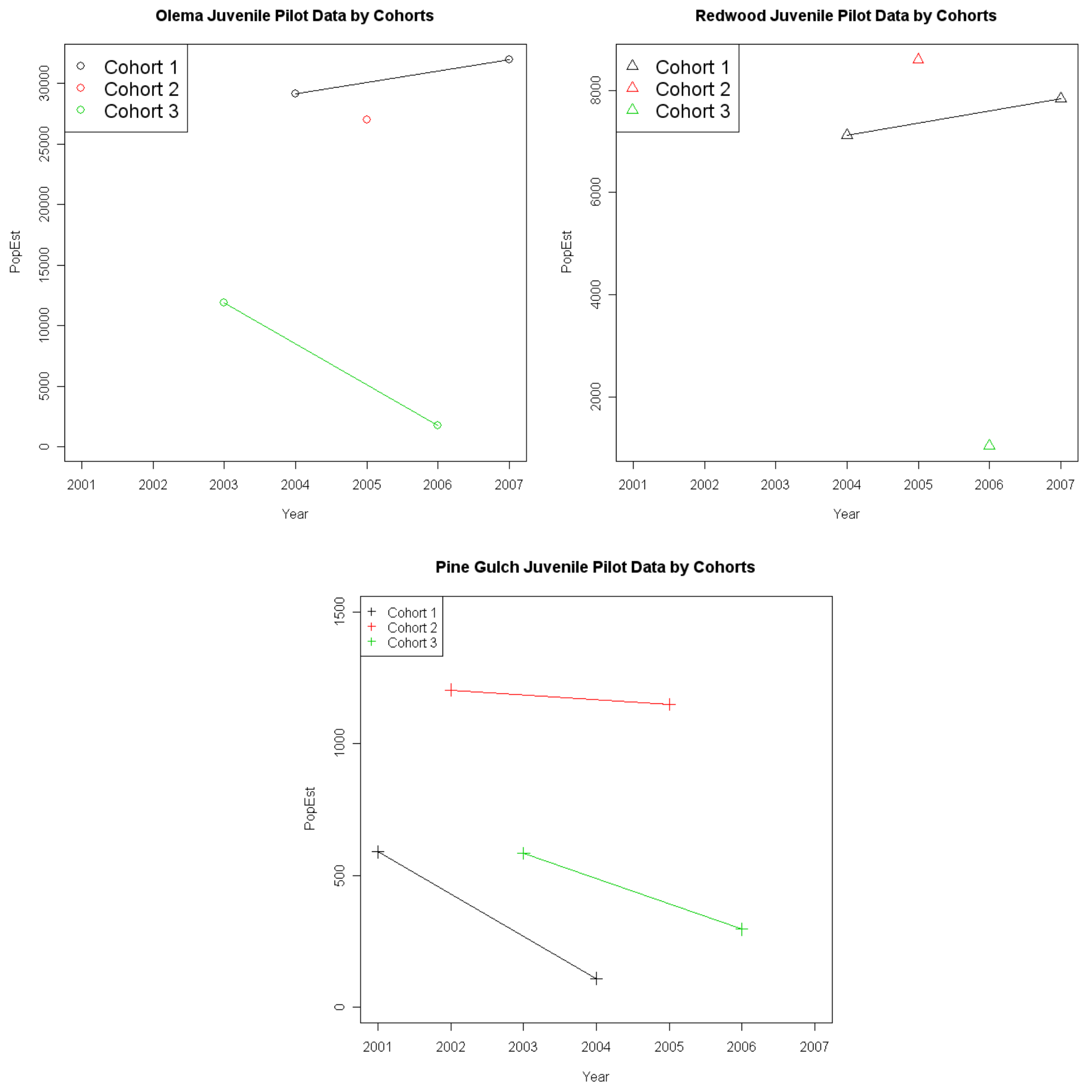
The abundance estimates are sparse (Table 1) and data are only balanced for survey years 2004 through 2007. Given the cohort structure, only the data from Pine Gulch Creek provides true replication for estimates of random effects of time. Fixed effects of watershed and cohort are estimated from the full data set of all three watersheds.

Table 1: Sample sizes for trend by watershed

Watershed	Number of survey years
Olema Creek	5
Pine Gulch Creek	7
Redwood Creek	5

Figure 1 displays the pilot data juvenile population estimates from the file *BasinWidePopEstimateforStat.xls* provided by SFAN. The top left panel displays the three cohorts in Olema Creek, the top right panel displays the three cohorts in Redwood creek, and the bottom panel displays the three cohorts in Pine Gulch creek.

Figure 1. Pilot Data Juvenile Basinwide Population Estimates for three watersheds.



As shown in Figure 1, only Pine Gulch has two years of data for each cohort; thus, for the power analysis for trend these data were used to estimate the random effects of time. Figure 1 also suggests preliminary evidence of a creek by cohort effect. The ordering of cohorts within watersheds is not consistent. For example, cohort 1 (black line) is not always higher for all three watersheds.

Figure 2. Pilot Data Juvenile Basinwide Population Estimates Separated by Cohorts.

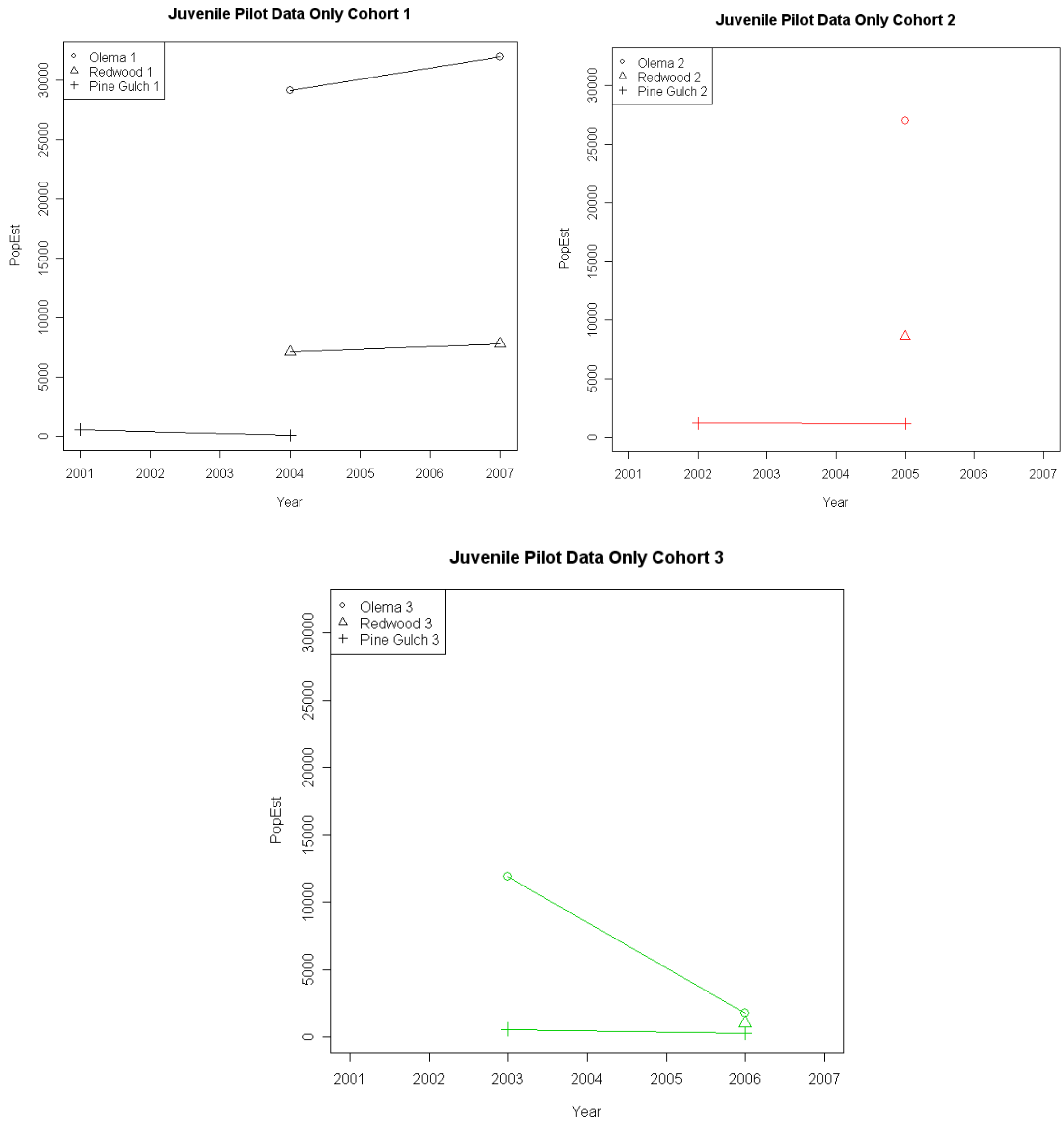


Figure 2 displays the three cohorts for each creek on a separate panel. Figure 2 suggests there is a difference between creeks for all three cohorts. Olema creek is consistently higher for all three cohorts (lines with circles). Pine Gulch consistently has the lowest population estimates (lines with crosses). This difference between creeks is modeled as a fixed creek effect in the trend model.

4.2 Trend Model

The mixed linear model of VanLeeuwen, et al. (1996) and Piepho and Ogutu (2002) is modified to reflect the cohort structure of juvenile Coho salmon. Assuming one population estimate per watershed per year, the modified linear mixed model is given by:

$$ln(y_{ijk}) = b_j + \alpha_i + w_j\beta + \mathrm{w}_j\, t_i + \gamma_\kappa + \phi_{ik} + w_j\, d_k + e_{ijk} \qquad (1)$$

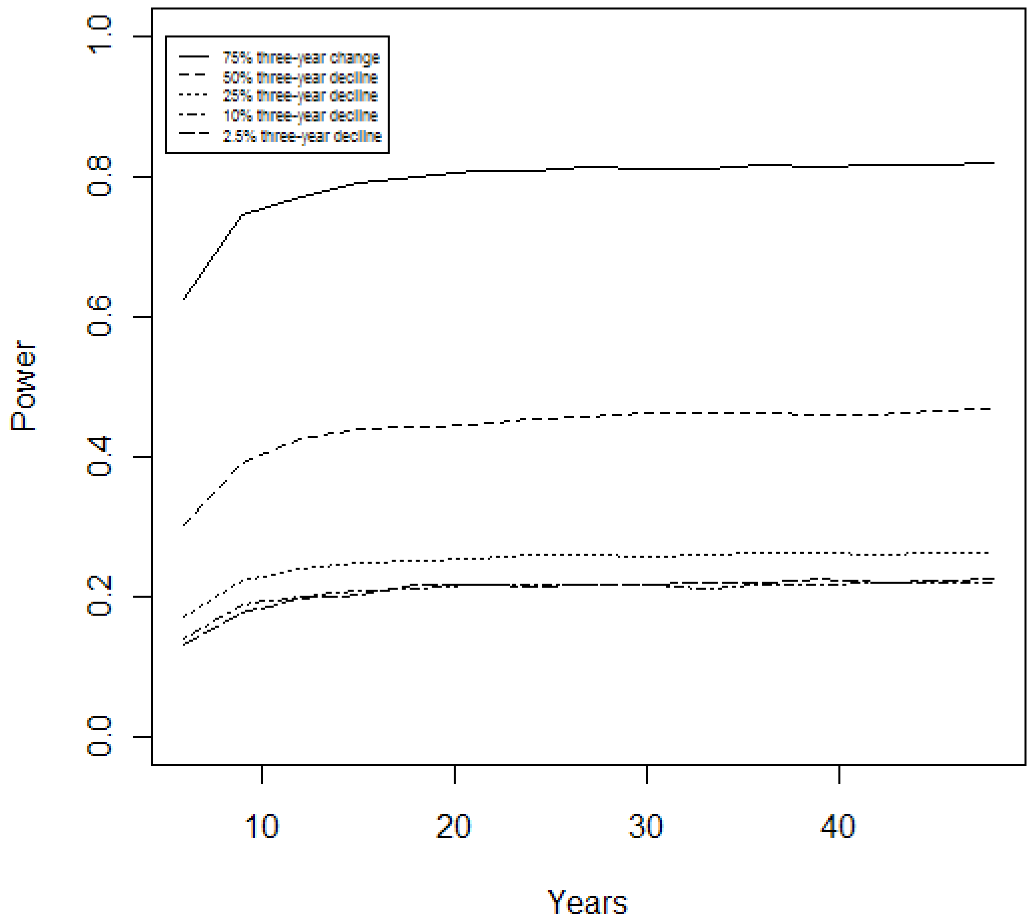
where $i = 1,\ldots, m_a$ indexes watershed;
$j = 1, \ldots, m_b$ indexes year;
$k = 1,2,3$ indexes the cohort;
m_a = the number of watersheds surveyed for juveniles ($m_a = 3$);
m_b = the number of years of sampling;
y_{ijk} = Basinwide population estimate for juveniles in watershed i, year j, and cohort k.
b_j =random intercept of the j^{th} year, iid as $N(0, \sigma^2_{\mathrm{b}})$;
α_i = the fixed intercept of the i^{th} watershed;
β = fixed slope of the linear time trend;
w_j = is a constant representing the *jth* cohort-by-watershed year;
t_i = random slope of i^{th} watershed, iid as $N(0, \sigma^2_{\mathrm{t}})$;
γ_{k} = fixed intercept of k^{th} cohort;
ϕ_{ik} = the fixed interaction between the i^{th} watershed and k^{th} cohort;
d_k = random slope for the k^{th} cohort, iid as $N(0, \sigma^2_{\mathrm{d}})$; and
e_{ijk} = unexplained error, iid as $N(0, \sigma^2_{\mathrm{e}})$.

This linear model forms the basis of the power analysis for the test of the fixed effect for CCYear. Tests were performed at the α=0.10 level. The pilot data are too sparse for estimation of all random effects, so only σ^2_{d} and σ^2_{e} were estimated for the power analysis. Actual power to detect trend in the estimates of juvenile abundance under the current estimation process will be slightly lower than the results below indicate.

4.3 Results

Simulations were conducted in R to generate random effects and assess the power to detect actual trends over time. The two-sided hypothesis test of no trend was calculated for three-year multiplicative **decreases** of 2.5%, 10%, 25%, 50%, and 75%. The results of the power for tests of trend for juvenile population estimates are given in Figure 3. Power to detect changes in the juvenile estimates of abundance is low for all but the most extreme population declines.

Figure 3: Power for test of trend for juvenile abundance estimates



5. Recommendations

1. Modify sampling design to annually incorporate true subsample of systematic sites to use for calibration.
2. If annual subsamples are not possible, conduct pilot study every 3 to 5 years to assess bias of ratio estimator based on index reaches only and use methods outlined by Elliot and Haviland (2007) to compute composite estimator of abundance from both systematic sites and index reaches. Use true subsamples to obtain abundance estimates as in Hankin and Reeves (1988). Use this estimate of abundance to compute an estimate of relative bias for the estimate computed using the index reach pools as the calibration data set. The relative bias may be used to correct estimates from years in which a true subsample is not available. An additional variance component will be needed to account for the relative bias adjustment.

3. Based on our recommendations 1 and 2, the power analysis for trend should be re-evaluated once there is data available from a statistically defensible sampling design. The results in this report are only preliminary for that reason.

6. References

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